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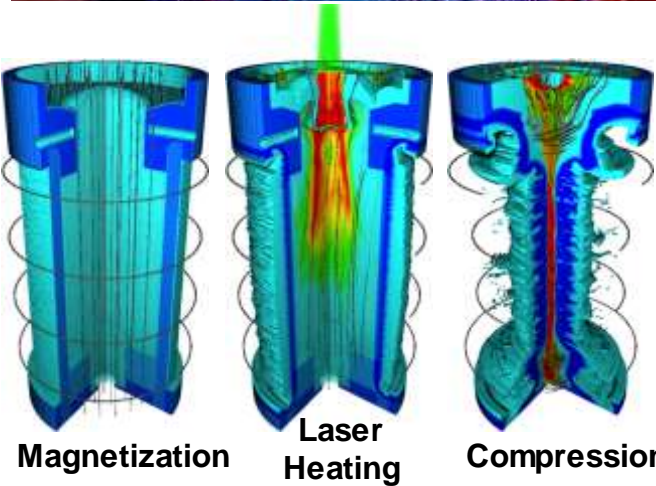
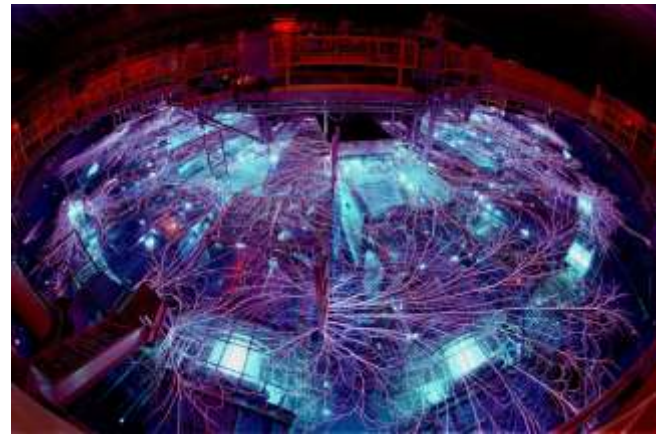


# Demonstrating Fuel Magnetization and Laser Heating Tools for Low-Cost Fusion Energy (Part 1)

Daniel B. Sinars

*Sandia National Laboratories,  
Albuquerque, NM, USA*

*ARPA-E ALPHA Kickoff Meeting  
Oct. 14-15, 2015  
Santa Fe, NM, USA*



Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

# This 2-year, \$4M project is a joint collaboration between Sandia and the University of Rochester



## ■ Sandia National Laboratories, Albuquerque, NM

- Daniel Sinars\*, Senior Manager, Radiation & Fusion Physics Group
- Kyle Peterson\*, Manager, ICF Target Design Department
- John Porter\*, Manager, Laser Operations & Engineering
- Matthias Geissel, Principal Member of Technical Staff
- Adam Harvey-Thompson, Akima Infrastructure Services
- Adam Sefkow, Principal Member of Technical Staff
- Stephen Slutz, Distinguished Member of Technical Staff

## ■ University of Rochester, Rochester, NY

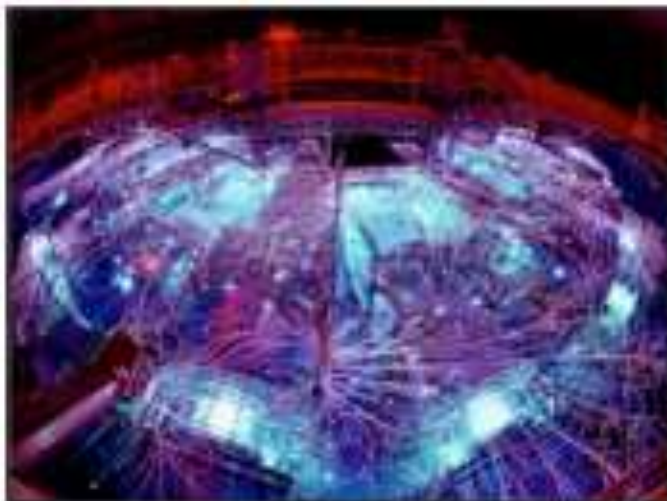
- Riccardo Betti\*, Director, Fusion Science Center
- Mike Campbell\*, Deputy Director of Laboratory for Laser Energetics
- Jonathan Davies\*, Research Scientist
- Po-Yu Chang, Postdoctoral Associate
- Sean Regan, Group Leader of Omega Experiments
- Dan Barnak, Graduate Student

\* In attendance today

# This project will utilize existing capabilities at both institutions to demonstrate magneto-inertial fusion scaling

## Sandia National Laboratories

- 80-TW, 20 MJ Z pulsed power facility
- 1-TW, multi-kJ Z-Backlighter laser facility
- 30 T B-field system (900 kJ stored energy)

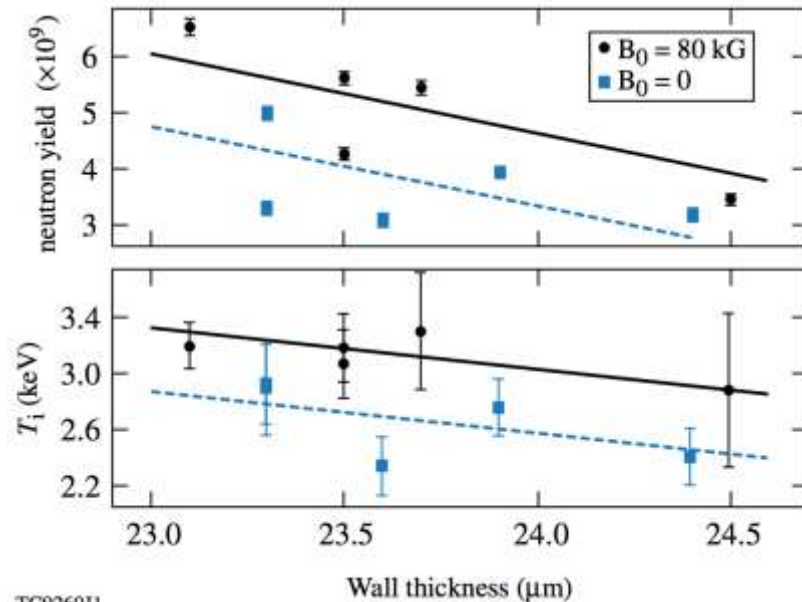
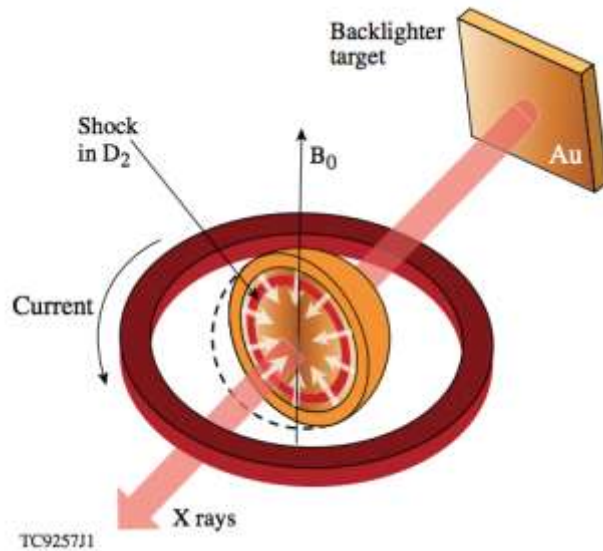


## Laboratory for Laser Energetics

- 60-beam, 30-TW, 30 kJ, OMEGA laser facility
- 4-beam, TW to PW, multi-kJ OMEGA-EP laser facility
- 20 T B-field systems (200 J stored energy)

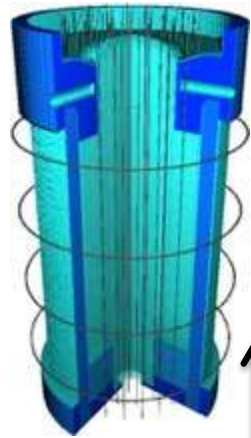


# Recent laser-driven spherical capsule implosions\* showed higher temperatures (and yields) due to fuel magnetization



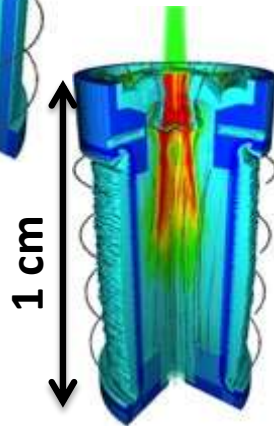
- Simple axial field used in a spherical implosion geometry
- Field suppressed electron heat conduction losses along one direction
- The resulting 15% increase in temperature and 30% increase in yield is consistent with estimates for transverse heat loss suppression
- This is an example of success with a target that produced fusion yield without magnetization—can we produce yield in targets that would not produce significant yield otherwise?

# This project is centered around the Magnetized Liner Inertial Fusion (MagLIF) target design for Z



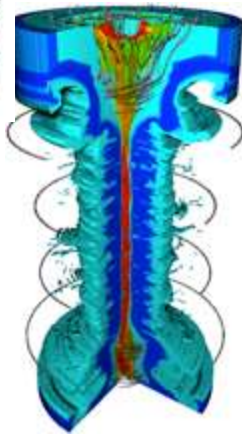
## Axial Magnetic Field (10 T initially; 30 T available)

- Inhibits thermal losses from fuel to liner
- May help stabilize liner during compression
- Fusion products magnetized



## Laser heated fuel (2 kJ initially; 6-10 kJ planned)

- Initial average fuel temperature 150-200 eV
- Reduces compression requirements ( $R_o/R_f \sim 25$ )
- Coupling of laser to plasma in an important science issue



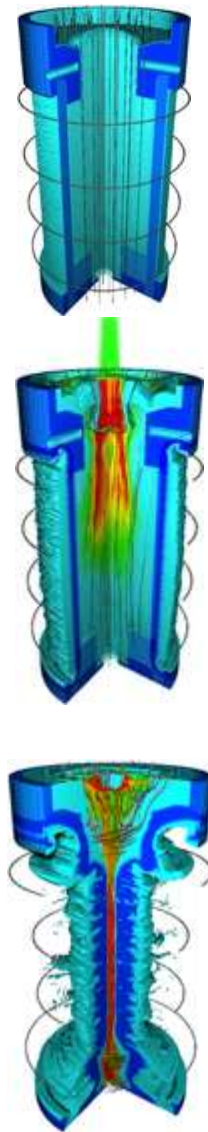
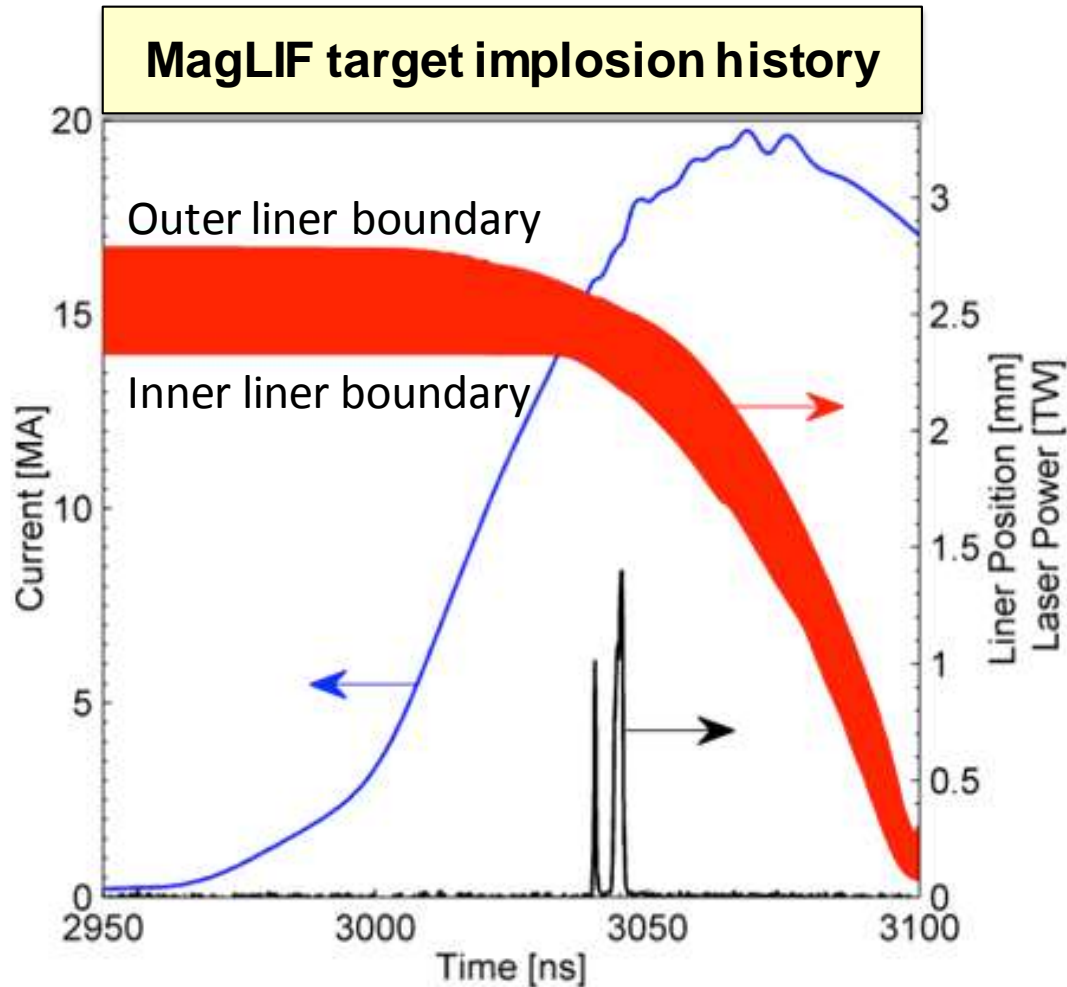
## Magnetic compression of fuel ( $\sim 100$ kJ into fuel)

- $\sim 70$ - $100$  km/s, quasi-adiabatic fuel compression
- Low Aspect liners ( $R/\Delta R \sim 6$ ) are robust to hydrodynamic (MRT) instabilities
- Significantly lower pressure/density than ICF

Goal is to demonstrate scaling:  $Y(B_{z0}, E_{laser}, I)$   
DD equivalent of 100 kJ DT yield possible on Z



# This project will use multiple facilities to demonstrate MagLIF scaling & laser heating



## Initial Conditions

- Be liner
- $\rho_{DT} \sim 1\text{-}4 \text{ mg/cc}$
- $B_{z0} \sim 10\text{-}30 \text{ T } (\sim 0.1 \text{ MG})$

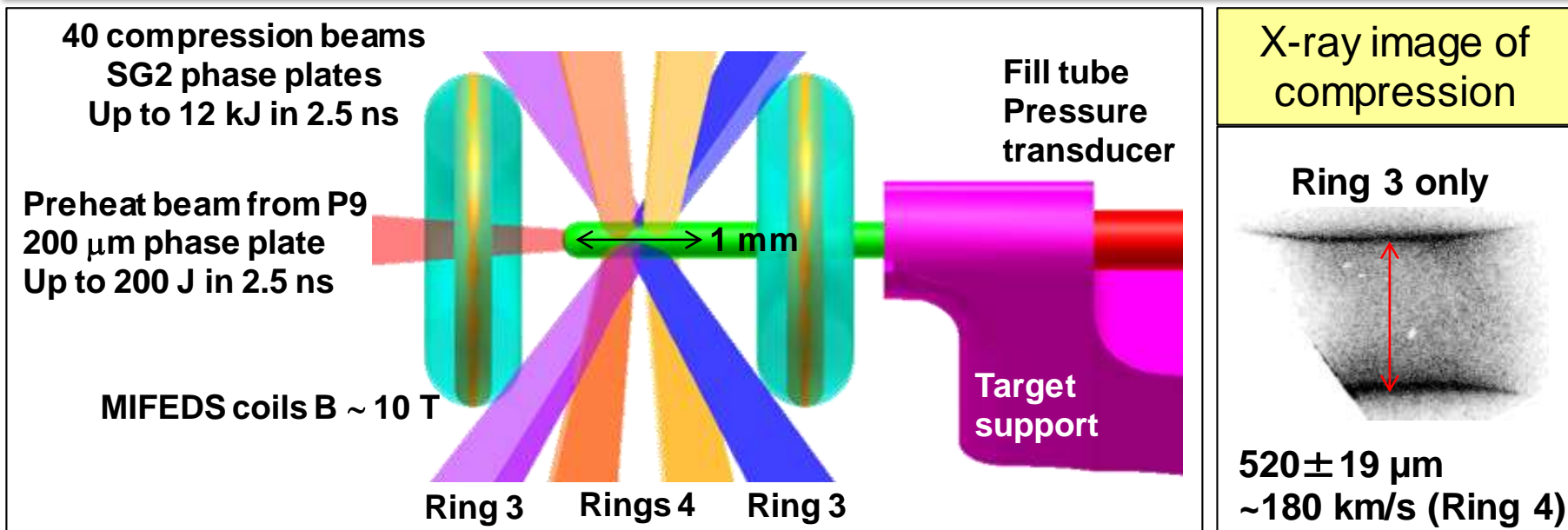
## Laser Heating

- $E_{\text{laser}} \sim 2\text{-}6 \text{ kJ @ } .53\mu\text{m}$
- $T_{DT} \sim 0.2 \text{ KeV}$
- $\omega\tau \sim 2\text{-}5$
- Research on Z, ZBL, Omega, Omega-EP

## Implosion/stagnation

- $V_{\text{imp}} \sim 70\text{-}100 \text{ km/sec}$
- $P_{DT} \sim 5 \text{ Gbar}$
- $T_{\text{ion}} > 5 \text{ keV}$
- $\omega\tau \sim 200 (B \sim 100 \text{ MG})$
- Research on Z, Omega

# A design for laser-driven MagLIF on OMEGA has been developed and will be demonstrated in the next 2 years



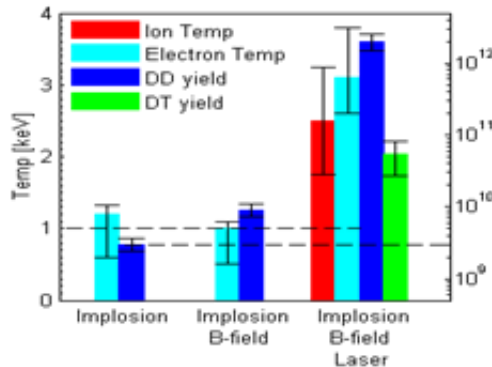
## Parylene-N Target

Outer diameter:	600 $\mu\text{m}$	D <sub>2</sub> fill density:	1 – 2.1 mg/cc
Shell thickness:	30 $\mu\text{m}$	Preheat temperature:	$\geq 100$ eV
Compressed length:	600 – 700 $\mu\text{m}$		

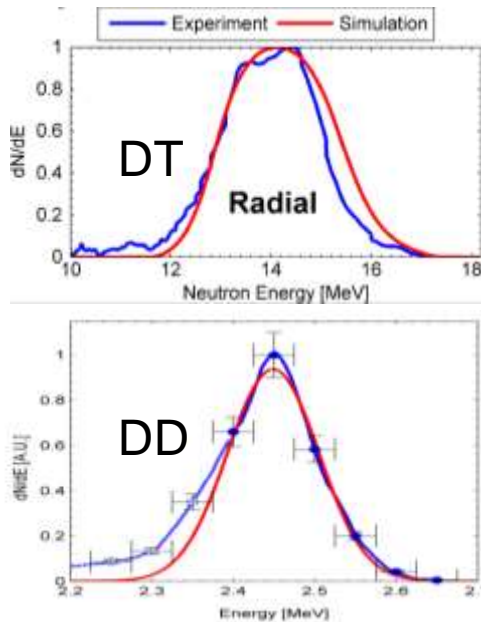
- Experiments in 2015 have established that we can couple the laser to the target and heat it all the way through to  $>100$  eV
- We have achieved cylindrical compression at the desired implosion velocity, and are now optimizing the axial uniformity and compressed length

# This project will benefit from extensive diagnostic capabilities available on our facilities that tell us more than just the yield

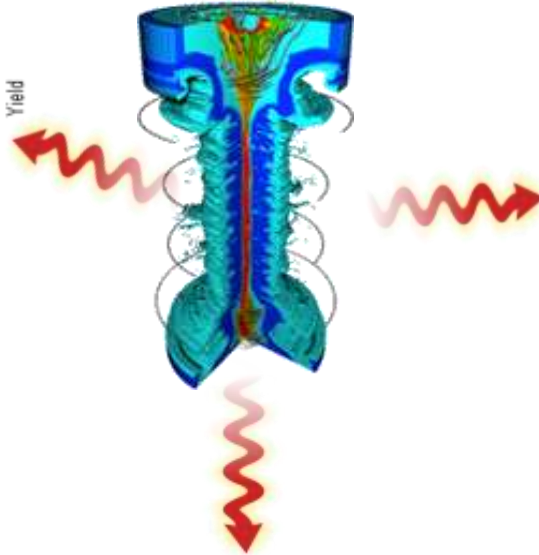
## Nuclear Activation (yield)



## Neutron spectra (Tion)



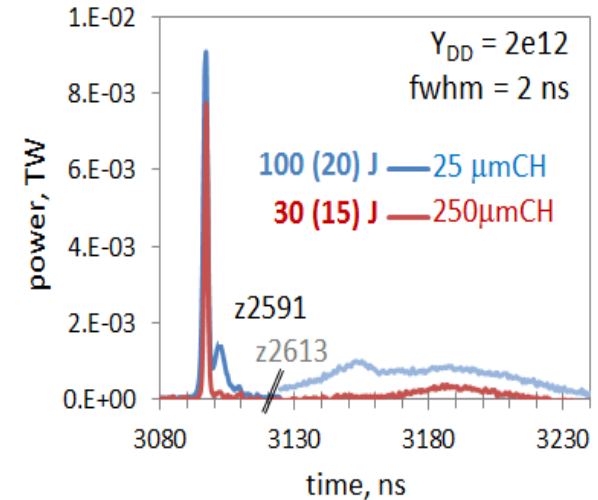
## MagLIF Z pinch



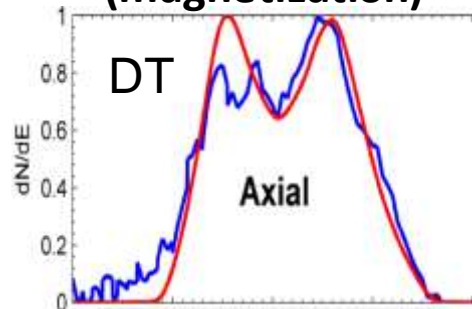
## X-ray Imaging (hot plasma shape)



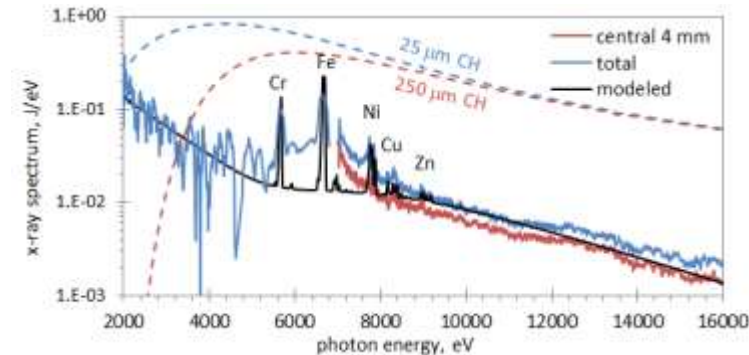
## X-ray Power (duration)



## DT Neutron spectra (magnetization)



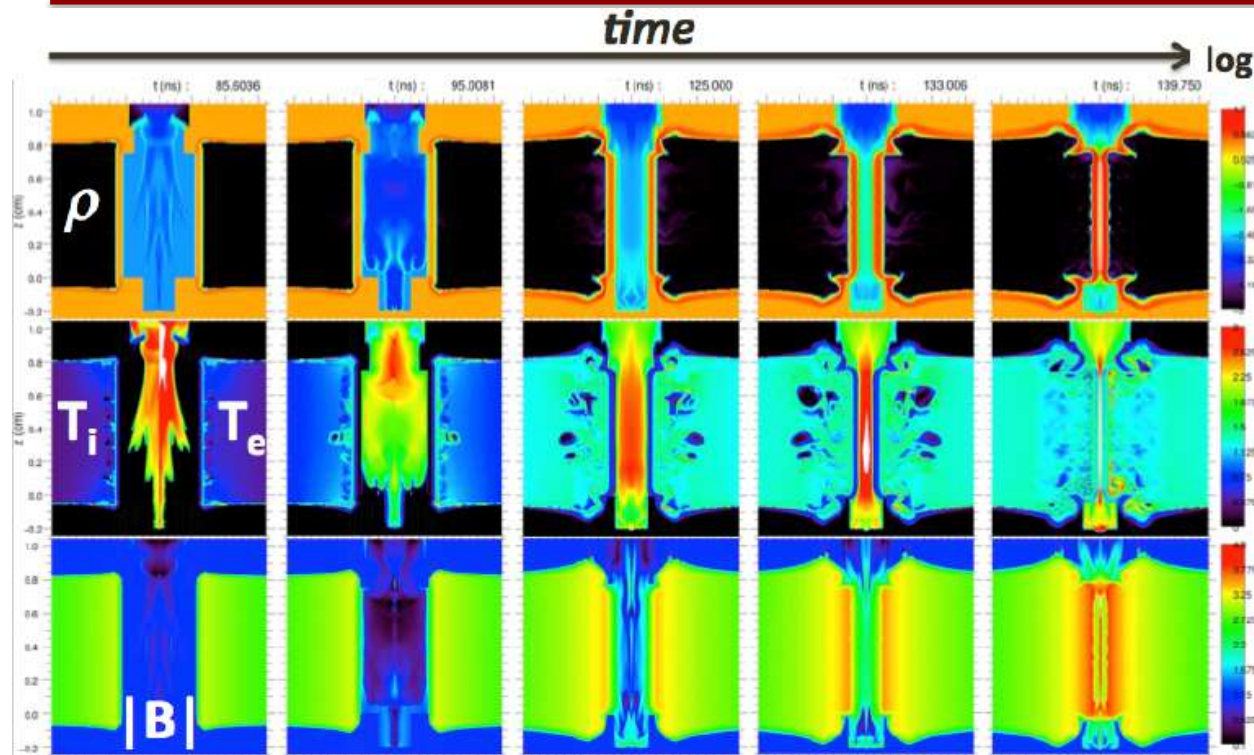
## X-ray Spectra (Te, mix)



Other unique diagnostics (e.g., proton radiography for Bfield measurement at OMEGA)



This project will benefit from expertise in theory and 2D/3D modeling capabilities available to participants



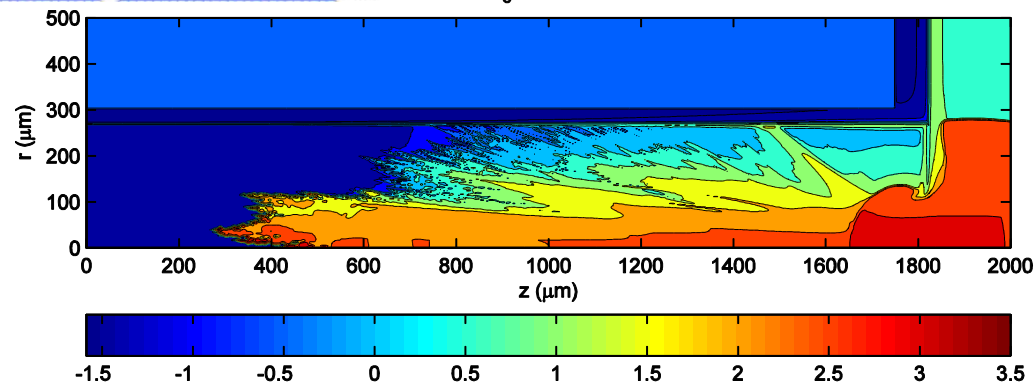
Codes in use by team:

LASNEX  
HYDRA  
LSP  
LILAC  
DRACO  
FLASH

OMEGA laser heating  
(DRACO)\*\*

log[T<sub>e</sub> (eV)] at 0.4 ns

Z MagLIF target (HYDRA)\*



\* A.B. Sefkow, S.A. Slutz *et al.*, Phys. Plasmas 21, 072711 (2014); \*\* J.R. Davies *et al.*

# Our project will demonstrate magneto-inertial fusion in relatively high-density, short-duration plasmas, and study the scaling of magneto-inertial fusion using modeling

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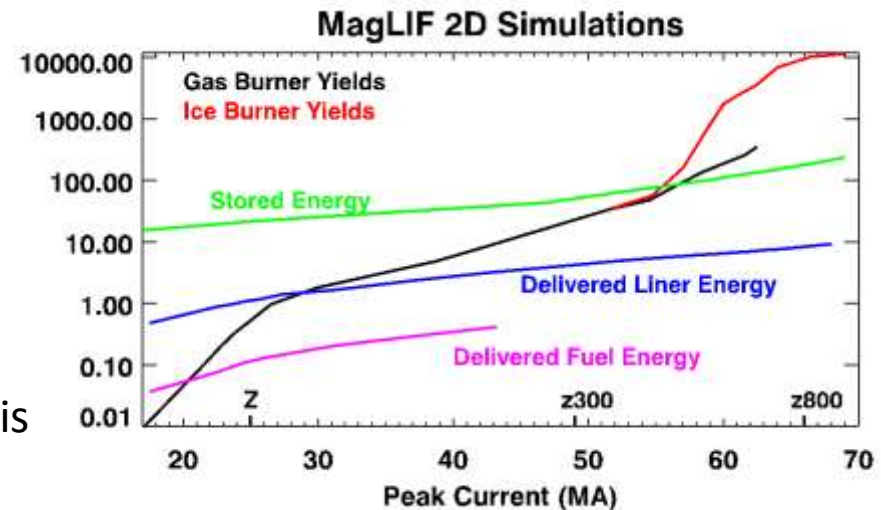
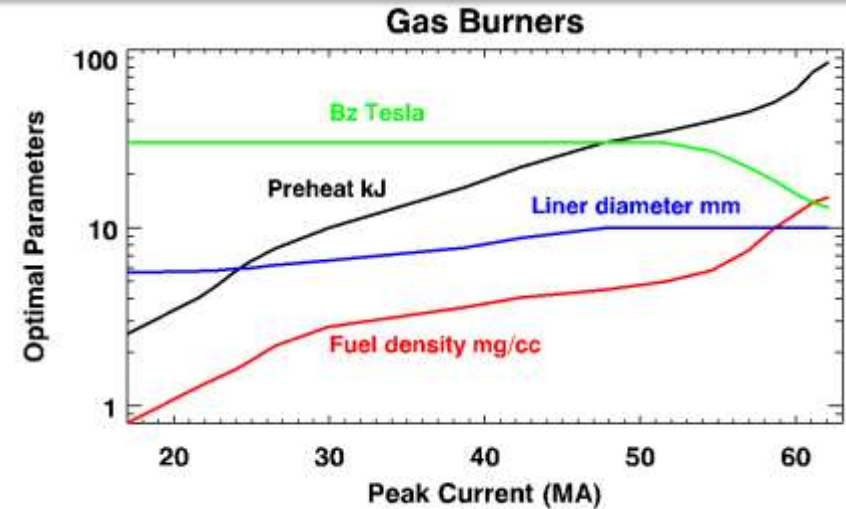
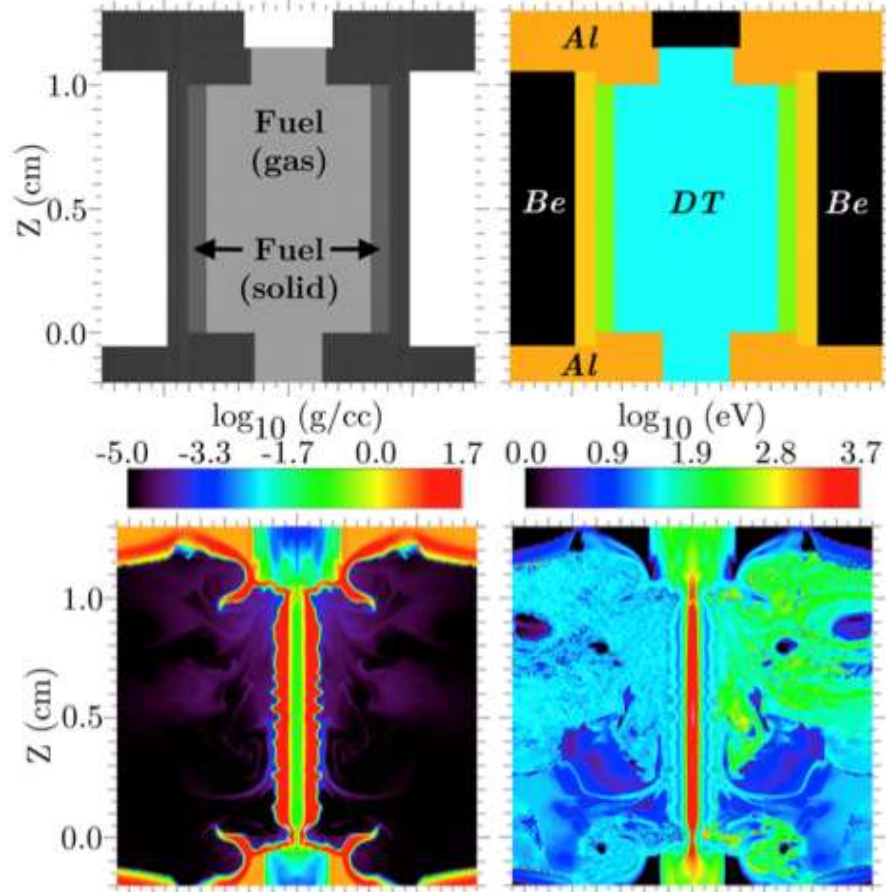
- **Target pre-conditioning experiments**
  - Needed to understand initial conditions for integrated Z, Omega shots
  - Will use Omega, Omega-EP, Z, Z-Backlighter
  - Will determine a set of conditions needed to achieve functional fuel pre-conditioning (i.e., laser and magnetic field configurations)
- **Laser-driven MagLIF experiments on OMEGA**
  - If successful, will demonstrate our ability to predict and scale the performance of magneto-inertial fusion targets over a wide range of size, time scale, and available energy (e.g., ~1 kJ to ~1 MJ absorbed)
- **Numerical Modeling & Theory**
  - Will improve & refine simulation models using data collected
  - Will apply benchmarked tools to examine MIF parameter space over a broad range exceeding that of near-term MagLIF experiments on Z
- **Tech transfer & Outreach activities**

# Z experiments have demonstrated thermal fusion with $>10^{12}$ 2.45 MeV neutrons from a $\sim 70$ km/s, $1.5$ mg/cm<sup>2</sup> implosion



- The initial MagLIF experiments on Z within the past 1.5 years demonstrated that there is merit to the idea of magneto-inertial fusion
- Laser heating of a magnetized initial plasma with minimal high-Z mix has been shown to be critical
  - Initial experiments used “unconditioned” beams and thick ( $>3$   $\mu$ m) foils and deposition into the gas was lower than expected
  - Low energy deposition and mix is borne out by several different experiments on multiple facilities
  - Simulations suggest a  $>100$  eV initial average plasma temperature (with low losses) would result in an order of magnitude increase in yield ( $\sim 8$  eV now?)
- **This project will greatly accelerate our progress with high shot rate\*:**
  - $\sim 100$ - $150$  shots/year on Z-Backlighter facility
  - $\sim 10$  shots/year using Z-Backlighter shooting into Z (different diagnostics)
  - $\sim 24$ - $30$  shots/year on OMEGA-EP [3 shot days/year]
  - $\sim 40$ - $50$  shots/year on OMEGA [4 shot days/year]
- **Present modeling predicts fusion yields of  $\sim 100$  kJ (DT) are possible on Z**

# Achieving energy-relevant yields will require extrapolation from existing facilities, so demonstrating credibility of our modeling tool predictions is important to ARPA-E



An intermediate regime exists wherein the  $B_z$  field is

- *strong enough* to reduce conduction losses, but
- *weak enough* not to inhibit the  $\alpha$  deflagration wave



# Questions?